(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 January 2001 (11.01.2001)

PCT

(10) International Publication Number
WO 01/03094 A1

(51) International Patent Classification[7]: G08B 17/117, 17/10, 21/00

(21) International Application Number: PCT/GB00/02410

(22) International Filing Date: 22 June 2000 (22.06.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9915388.4 2 July 1999 (02.07.1999) GB

(71) Applicant *(for all designated States except US)*: **THE SECRETARY OF STATE FOR DEFENCE** [GB/GB]; Defence Evaluation & Research Agency, Ively Road, Farnborough, Hampshire GU14 0LX (GB).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **CHAPMAN, Alan, David** [GB/GB]; DERA Haslar, CBSES, Gosport, Hampshire PO12 2AG (GB). **KNUTSEN, Linda, Christina** [GB/GB]; DERA Haslar, CBSES, Gosport, Hampshire PO12 2AG (GB). **RICHES, James, Robert** [GB/GB]; DERA Haslar, CBSES, Gosport, Hampshire PO12 2AG (GB).

(74) Agent: **BOWDERY, A., O.**; The Secretary of State For Defence, DERA Intellectual Property Dept., A4 Building, Rm GO16, Ively Road, Farnborough, Hampshire GU14 0LX (GB).

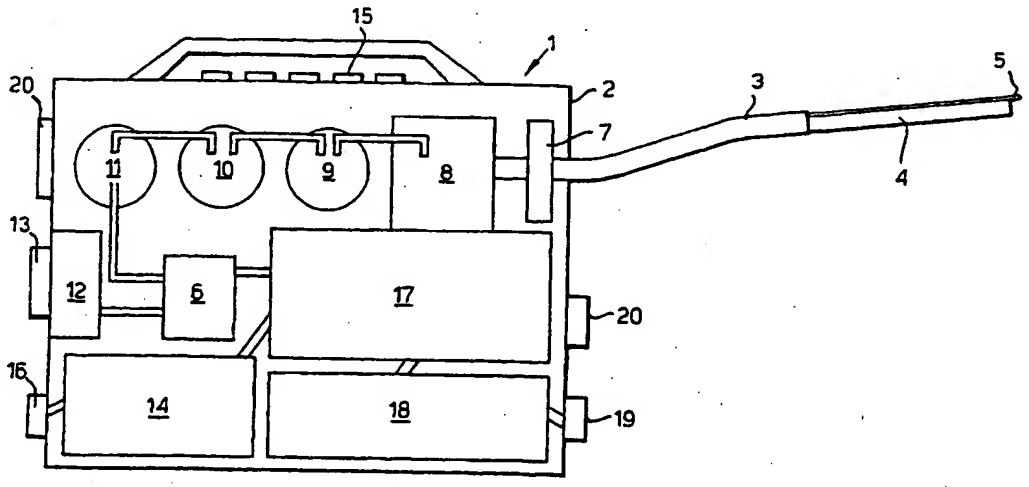
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: MONITORING SYSTEM



(57) Abstract: A monitoring system comprises a device to remotely sample the atmosphere (3) of a fire affected compartment to determine the temperature (5) and the relative concentrations of oxygen, carbon dioxide, carbon monoxide and flammable vapours (8, 9, 10, 12). A processor (14) is used to provide an indication of the safety status of the compartment (15) as safe to enter, unsafe to enter or undecided based on the determined gas concentrations and temperature.

WO 01/03094 A1

MONITORING SYSTEM

This invention relates to a monitoring system, for example for use in closed compartments, such as ships or tunnels.

In the event of a fire on a ship, which cannot be extinguished by automatic extinguishers or by personnel, the affected compartments are sealed. This is in order to prevent the spread of the fire to the rest of the ship and ensure the safety of the crew. The fire will then eventually self extinguish due to oxygen starvation. A decision must be made as to when the fire is out and it is safe to re-enter the compartment. If the fire is not completely extinguished, the re-admittance of oxygen caused by opening the compartment may result in a sudden intensification of the fire known as a 'flash over'. The decision as to whether the compartment is safe to enter has traditionally been made by monitoring the temperature of an outside surface of the compartment and insisting on a sustained decrease in temperature over an extended period. This method is both labourious and involves an element of uncertainty. Therefore, it is not failsafe.

GB 2,262,444A describes a system for the extinguishing and control of fires in an aircraft cargo bay. The system detects the onset of a fire and activates an automatic extinguisher system. Subsequent to this, the system remains active and monitors the temperature or the concentration of a selected gas in the cargo bay. If preset alarm levels of temperature or gas concentration are reached then the system releases further extinguishant to attempt to keep the fire under control. The object of this system is to control a fire in an aircraft cargo bay, ensuring the safety of the aircraft and its passengers whilst making the most efficient use of a limited supply of extinguishant. Once the aircraft has reached safe ground the passengers can be evacuated and there will usually be access to an unlimited supply of extinguishant to control the fire. There is never a requirement for personnel to enter the fire affected cargo bay and in extreme cases the fire can simply be left to burn. This may result in the loss of an aircraft, but does not put lives at risk. It is rarely possible to evacuate personnel from a ship at sea, so the usefulness of such a system in the case of a fire in a sealed ship compartment, as described above, is limited.

In accordance with the present invention a monitoring system comprises sampling means for remotely sampling the atmosphere of a fire affected compartment; analysing means for determining substantially simultaneously the relative concentrations of oxygen, carbon dioxide, carbon monoxide and flammable vapours in the sampled atmosphere; sensing means for remotely determining the

temperature of a fire affected compartment; processing means for processing the determined gas concentrations and temperature; and indicating means to indicate the safety status of the compartment as safe to enter, unsafe to enter or undecided according to the output of the processing means.

The system of the present invention is able to determine whether the fire has been extinguished, gives information about potential 'flash-over' situations and provides information regarding the safety of the atmosphere within the compartment i.e. whether breathing apparatus is required on re-entry. As the present invention determines and processes information about the temperature and the relative concentrations of all the gases in the compartment it is able to provide a detailed and reliable indication of its safety status. A simple prediction that the fire has gone out may not be adequate, for example a high carbon monoxide concentration or acid gas concentration may require that personnel take protective measures on re-entry to the affected compartment.

This is most acute when there is a potential 'flash over' situation. Prediction of this relies on a simultaneous indication of both the oxygen concentration and the level of flammable vapours. The present invention is able to provide this information thus substantially reducing or eliminating the risk of a 'flash over'.

The present invention allows the sealed compartment to be entered at the earliest safe opportunity, with the minimum risk. On a ship, this releases the crew to other tasks more quickly than using conventional methods which can be of great significance on fighting ships. For use in tunnels, this allows the clean up operation to begin sooner, reducing the loss of income due to the tunnel being closed.

Preferably, the analysing means comprises an oxygen sensor, a carbon dioxide sensor, a carbon monoxide sensor and a flammable vapour sensor.

Preferably, the oxygen sensor is an electrochemical sensor. These offer a wide range, have low power requirements and are unaffected by humidity. Alternatively, a paramagnetic oxygen sensor may be used.

Preferably, the carbon dioxide sensor comprises a solid state infra red sensor. These have low cross sensitivity and signal drift, with low power requirements and high reliability. Alternatively, other carbon dioxide sensors, such as electrochemical sensors, may be used.

Preferably, the carbon monoxide sensor comprises an electrochemical sensor. These have low power requirements and low signal drift. Alternatively, other carbon monoxide sensors, such as metal oxide semiconductor sensors or infra red sensors, may be used.

Preferably, the flammable vapour sensor comprises a calibrated pellistor gas sensor. These have high sensitivity, are robust and respond in a controlled and reliable fashion. Alternative flammable vapour sensors include metal oxide semiconductor sensors, such as a tin dioxide sensor, infra red sensors, thermal conductivity sensors and flame ionisation detectors.

Preferably, the system further comprises remotely sampling the atmosphere of a fire affected compartment and using an acid gas sensor to determine the concentration of acid gases, such as HCl, HF etc.

Many materials such as plastics, paints and other liquids produce acid gases when burnt. These can present a serious hazard to personnel entering the compartment.

Preferably, the acid gas sensor comprises an electrochemical sensor.

Preferably, the processing means comprises a knowledge based algorithm to determine whether the compartment is safe to enter, unsafe to enter or undecided.

Advantageously, the knowledge based algorithm returns a safe to enter indication when all of the following conditions are met: the concentration of flammable vapours is below 4vol% of the lower explosive limit (LEL); the concentration of carbon dioxide is below 2vol%; the concentration of oxygen is within the range 17 to 22vol%; the concentration of carbon monoxide is below 40 wppm; the concentration of acid gases is below 1 wppm; and the temperature is below 70°C.

Preferably, the algorithm returns an indication that the compartment may be entered with caution when any of the following conditions are met: the concentration of flammable vapours is equal to or above 4vol% LEL; the concentration of carbon dioxide is equal to or above 2vol%; the concentration of oxygen is outside the range 17 to 22vol%; the concentration of carbon monoxide is equal to or above 40 wppm; the concentration of acid gases is equal to or above 1 wppm; the temperature is equal to or above 70°C.

Preferably, the algorithm returns an unsafe to enter indication when the concentration of flammable vapours is equal to or above 4vol% LEL and the concentration of oxygen is below 17vol%.

Additionally, a high oxygen level indication is provided when the concentration of oxygen is equal to or above 22vol%.

Preferably, the processing means further determines substantially simultaneously the rate of change of the carbon dioxide concentration, the carbon monoxide concentration, the temperature and the oxygen concentration and provides a fire alight indication unless: the rate of change of the carbon dioxide concentration

has fallen below -0.005 vol% s^{-1}; or the rate of change of the carbon monoxide concentration has fallen below -1 wppm s^{-1}; or the rate of change of temperature has fallen below -0.1 °C s^{-1}; or the rate of change of the oxygen concentration is above 0.01vol% s^{-1}.

The levels and ranges of the gas concentrations and temperature used to trigger the safety status indicators are suitably set to ensure adequate safety margins. The figures quoted are in line with occupational health levels, however other levels may be chosen to suit a particular application.

Preferably, the indicating means comprises a series of light emitting diodes.

Advantageously, the indicating means further comprises a liquid crystal display panel.

Preferably, the atmosphere is sampled using a self contained unit; wherein the self contained unit comprises a sampling tube for insertion into the fire affected compartment; a pump to pass the sampled atmosphere through the sampling tube; an oxygen sensor, a carbon dioxide sensor, a carbon monoxide sensor and a flammable vapour sensor connected in series to determine the relative concentrations of the gases in the sampled atmosphere; a temperature probe attached to the sampling tube to determine the temperature of the affected compartment; processing means for processing the determined gas concentrations and temperature; indicating means to indicate the safety status of the compartment as safe to enter, unsafe to enter or undecided according to the output of the processing means; data storage means to store the values for the relative gas concentrations and temperature; and an interface to enable the stored values to be downloaded to an external computer system for further processing.

A self contained unit has the advantage that it can be taken to the fire affected compartment when required. This avoids the complication and expense of installing individual systems in each of possibly numerous compartments. The facility to be able to monitor the safety status of the compartment remotely without the need to enter the compartment also helps to ensure the safety of operators, emergency services and personnel.

Preferably, the temperature probe comprises a thermocouple.

Preferably, the system further comprises an infra red camera which is used to visually assess the state of the fire. Alternatively a thermal imaging camera may be used, however this type of camera is much more expensive.

If required, the system may be interfaced to a locking mechanism on the affected compartment such that entry to the compartment is prevented until the system decides that it is safe to enter.

The invention will now be described by way of example only with reference to the accompanying drawing in which:

Figure 1 shows a diagrammatic representation of a monitoring system in accordance with the present invention.

The system 1 comprises a rigid case 2 with carrying handle to which is connected a flexible sampling hose 3. Attached to the end of the sampling hose is a rigid probe 4 to facilitate access to a fire affected compartment. The rigid probe further comprises a thermocouple 5. In use, a sample of the atmosphere from a fire affected compartment is pumped into the system by a pump 6, through a filter 7 and then, in series, through a solid state infra red carbon dioxide sensor 8, an electrochemical carbon monoxide sensor 9, an electrochemical oxygen sensor 10, and an electrochemical acid gas sensor 11. The sampled gas then passes through the pump 6 and a pellistor flammable vapour sensor 12, before being expelled through an exhaust 13. Readings from the gas sensors and the thermocouple are fed to a signal processing unit 14 where a knowledge based algorithm is used to determine whether the compartment is safe to enter. The output from the algorithm is displayed by a series of LED indicators 15. Alternatively, data from the signal processing unit can be downloaded to an external computer system via an RS232 communications port 16 and the results displayed on the computer monitor. In this example, the system is powered by a rechargeable power supply comprising a battery pack 17, a power supply/battery charging unit 18 and a mains supply socket 19. An adequate flow of ambient air through the system is provided by air diffusion membranes 20.

Example 1.

A fire was set alight in a sealed chamber and the atmosphere monitored using a system according to the present invention. Table 1 shows the values obtained from the sensors and the decisions reached by the system.

Table 1.

time ► / sensor ▼	initial	2 min	4 min	8min
[CO] / wppm	322	387	347	30.4
[CO_2] / vol%	1.37	1.54	1.30	0.20
[O_2] / vol%	17.9	17.7	18.2	20.1
[flam.] / vol%	0.41	0.42	0.41	0.39
[HCl] / wppm	0.20	0.20	0.20	0.20
temp. / °C	63	69	49	19.7
safety status ► / rate of change ▼	CAUTION	CAUTION	CAUTION	SAFE
$\frac{\partial[CO]}{\partial t}$ wppm s^{-1}	2.01	-1.04	-	-
$\frac{\partial[CO_2]}{\partial t}$ vol% s^{-1}	0.005	-0.002	-	-
$\frac{\partial[O_2]}{\partial t}$ vol% s^{-1}	-0.005	0.015	-	-
$\frac{\partial T}{\partial t}$ °C s^{-1}	0.301	-0.125	-	-
fire status ►	FIRE	FIRE OUT	FIRE OUT	FIRE OUT

Initially, the concentration of CO is above the safe limit of 40 wppm, whereas all other sensors show safe readings. The system returns an 'enter with caution' response. The rate of change of the CO concentration, CO_2 concentration and temperature are all above alarm levels and the rate of change of the O_2 concentration is below the alarm level. The system, therefore returns a 'fire alight' response.

After 2 minutes the CO concentration remains above the safe limit of 40 wppm and thus the 'enter with caution' indication persists, however as the rate of change variables are all now within the safe zones, the system returns a 'fire out' response.

There is no change in status after 4 minutes. Although the concentration of CO is falling, it is not below safety limits, so the chamber should still only be entered with caution, for example, using breathing apparatus. The fire remains out.

After 8 minutes all sensors give readings which are within the safe zones. The system returns a 'safe to enter' indication and the compartment can be entered without the need for breathing apparatus. The fire remains out.

The system is thus able to remotely determine the safety status of a compartment which is affected by fire. A clear indication of whether the fire has been extinguished and whether the compartment is safe to re-enter is provided. This removes the need for a judgement to be made and is therefore failsafe.

The system, although suited for use in the event of a fire in a ship compartment, can equally be used to determine the safety status of any fire affected space such as a room in a building, a storage area or an underground space such as a mine or a tunnel.

In the event of a fire in a rail or road tunnel it is often possible to seal off the fire affected area. This prevents the fire from spreading and facilitates the safe evacuation of personnel and vehicles. The use of a monitor according to the present invention would allow a decision to be made as to whether the fire was extinguished and when the danger of a 'flash over' had subsided. In addition to the obvious safety implications there would also be economic benefits arising from the timely reopening of the tunnel as soon as the situation was found to be safe.

CLAIMS

1. A monitoring system comprising sampling means for remotely sampling the atmosphere of a fire affected compartment; analysing means for determining substantially simultaneously the relative concentrations of oxygen, carbon dioxide, carbon monoxide and flammable vapours in the sampled atmosphere; sensing means for remotely determining the temperature of a fire affected compartment; processing means for processing the determined gas concentrations and temperature; and indicating means to indicate the safety status of the compartment as safe to enter, unsafe to enter or undecided according to the output of the processing means.

2. A system according to claim 1, wherein the analysing means comprises an oxygen sensor, a carbon dioxide sensor, a carbon monoxide sensor and a flammable vapour sensor

3. A system according to claim 2, wherein the oxygen sensor comprises an electrochemical sensor; the carbon dioxide sensor comprises a solid state infra red sensor; the carbon monoxide sensor comprises an electrochemical sensor; and the flammable gas sensor comprises a calibrated pellistor gas sensor.

4. A system according to any of claims 1 to 3, wherein the analysing means further comprises an acid gas sensor.

5. A system according to claim 4, wherein the acid gas sensor comprises an electrochemical sensor.

6. A system according to any of claims 1 to 5, wherein the processing means comprises a knowledge based algorithm to determine whether the compartment is safe to enter, unsafe to enter or undecided.

7. A system according to any preceding claim, wherein a safe to enter indication is provided when all of the following conditions are met: the concentration of flammable vapours is below 4vol% of the lower explosive limit (LEL); the concentration of carbon dioxide is below 2vol%; the concentration of oxygen is within

the range 17 to 22vol%; the concentration of carbon monoxide is below 40 wppm; the concentration of acid gases is below 1 wppm; and the temperature is below 70°C.

8. A system according to any preceding claim, wherein an indication that the compartment may be entered with caution is provided when any of the following conditions are met: the concentration of flammable vapours is equal to or above 4vol% LEL; the concentration of carbon dioxide is equal to or above 2vol%; the concentration of oxygen is outside the range 17 to 22vol%; the concentration of carbon monoxide is equal to or above 40 wppm; the concentration of acid gases is equal to or above 1 wppm; the temperature is equal to or above 70°C.

9. A system according to any preceding claim, wherein an unsafe to enter indication is provided when the concentration of flammable vapours is equal to or above 4vol% LEL and the concentration of oxygen is below 17vol%.

10. A system according to any preceding claim, wherein the processing means further determines substantially simultaneously the rate of change of the carbon dioxide concentration, the carbon monoxide concentration, the temperature and the oxygen concentration.

11. A system according to claim 10, wherein a fire alight indication is provided unless: the rate of change of the carbon dioxide concentration has fallen below -0.005 vol% s^{-1}; or the rate of change of the carbon monoxide concentration has fallen below -1 wppm s^{-1}; or the rate of change of temperature has fallen below -0.1 °C s^{-1}; or the rate of change of the oxygen concentration is above 0.01vol% s^{-1}.

12. A system according to any preceding claim, wherein the indicating means comprises a series of light emitting diodes.

13. A system according to any preceding claim, wherein the system comprises a self contained unit.

14. A system according to claim 13, wherein the self contained unit comprises a sampling tube for insertion into the fire affected compartment; a pump to pass the sampled atmosphere through the sampling tube; an oxygen sensor, a carbon dioxide sensor, a carbon monoxide sensor and a flammable vapour sensor connected in

series to determine the relative concentrations of the gases in the sampled atmosphere; a temperature probe attached to the sampling tube to determine the temperature of the affected compartment; processing means for processing the determined gas concentrations and temperature; indicating means to indicate the safety status of the compartment as safe to enter, unsafe to enter or undecided according to the output of the processing means; data storage means to store the values for the relative gas concentrations and temperature; and an interface to enable the stored values to be downloaded to an external computer system for further processing.

15. A system according to claim 14, wherein the temperature probe comprises a thermocouple.

16. A system according to any preceding claim, wherein the system further comprises an infra red camera.

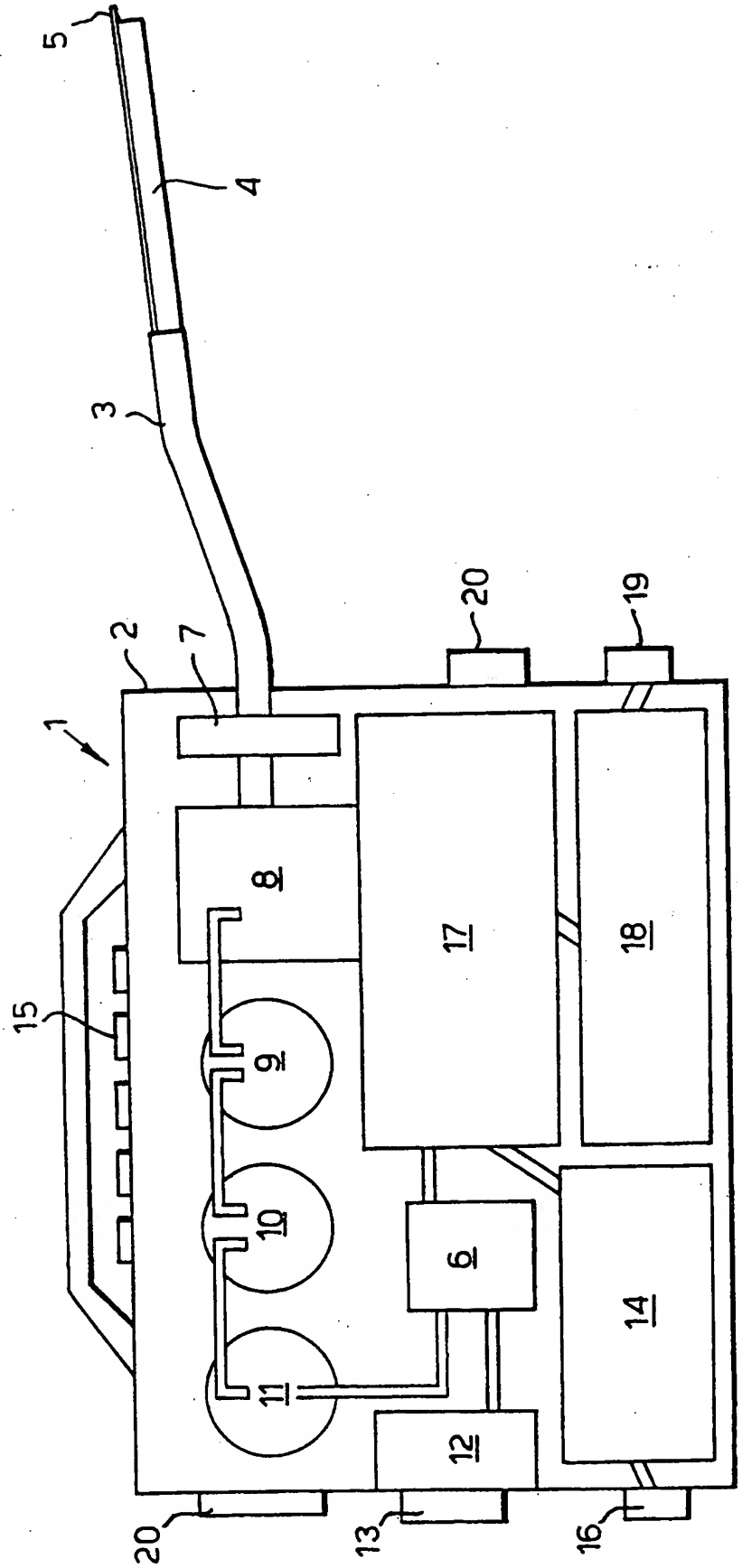


Fig.1.

INTERNATIONAL SEARCH REPORT

Interna nal Application No
PCT/GB 00/02410

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G08B17/117 G08B17/10 G08B21/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G08B A62C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 486 811 A (WEHRLE JOHN P ET AL) 23 January 1996 (1996-01-23)	1
Y	column 5, line 27 -column 7, line 14	12,13
P,Y	US 5 966 078 A (TANGUAY WILLIAM PETER) 12 October 1999 (1999-10-12) table 2	12,13
A	EP 0 421 100 A (PREUSSAG AG FEUERSCHUTZ) 10 April 1991 (1991-04-10) column 7, line 37 - line 58	1
A	FR 2 724 247 A (SCHEEFER GERARD) 8 March 1996 (1996-03-08) the whole document	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 September 2000	09/10/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De la Cruz Valera, D

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

...ormation on patent family members

Intern... ...al Application No
PCT/GB 00/02410

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5486811 A	23-01-1996	NONE	
US 5966078 A	12-10-1999	US 5969600 A	19-10-1999
		US 5886638 A	23-03-1999
		US 5966079 A	12-10-1999
		US 5912626 A	15-06-1999
		US 5896091 A	20-04-1999
EP 0421100 A	...0-04-1991	DE 4023649 A	21-02-1991
		DE 59003229 D	02-12-1993
		ES 2047780 T	01-03-1994
FR 2724247 A	08-03-1996	AU 3261495 A	22-03-1996
		DE 69509536 D	10-06-1999
		DE 69509536 T	23-12-1999
		EP 0777896 A	11-06-1997
		ES 2133794 T	16-09-1999
		WO 9607166 A	07-03-1996